SUNPOWER™

THE WORLD'S STANDARD FOR SOLAR™

DG Integration

Carl Lenox

September 14th, 2012

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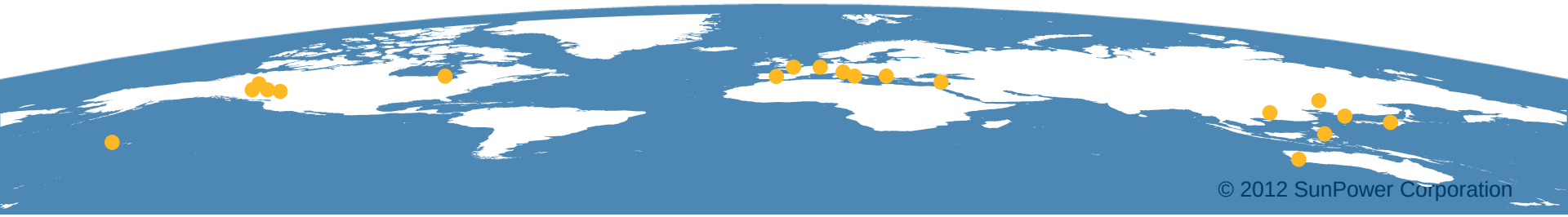
SunPower 2012

- World-leading solar conversion efficiency
- >2.5 GW solar PV deployed
- Diversified portfolio: roofs to power plants
- More than 200 patents
- 6,000+ employees
- Strategic investment by Total: #11, F500



Example “Utility Scale” Power Plants

Greater Sandhill, Mosca, Colorado
19 MW SunPower T20 Tracker

California Valley Solar Ranch, San Luis Obispo County, 250 MW
SunPower Oasis T0 Tracker

Apple, Maiden NC Data Center
20 MW SunPower T0 Tracker

Montalto Di Castro, Lazio, Italy
84 MW SunPower T0 Tracker

Exelon City Solar, Chicago, Illinois
10 MW SunPower T0 Tracker

DeSoto, Arcadia, Florida
25 MW SunPower T0 Tracker

Highly Distributed PV

- 15% technical “limit” or cap is a myth.
- Interconnection study may be triggered
  -- can be a market barrier.
- California recently reformed Rule 21 to address
- FERC considering whether to follow suit
- Reactive power control can significantly improve “hosting capacity” of the distribution system
- Limited curtailment also an option
- Storage not typically an economic solution

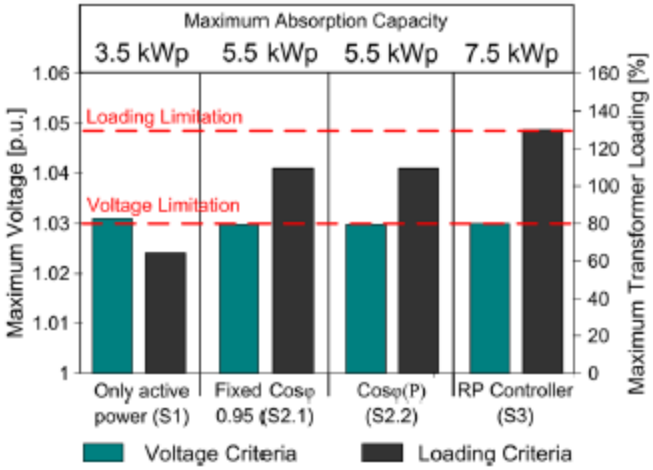


Figure 4. Maximum hosting capacity of the investigated low-voltage network for photovoltaic capacity.

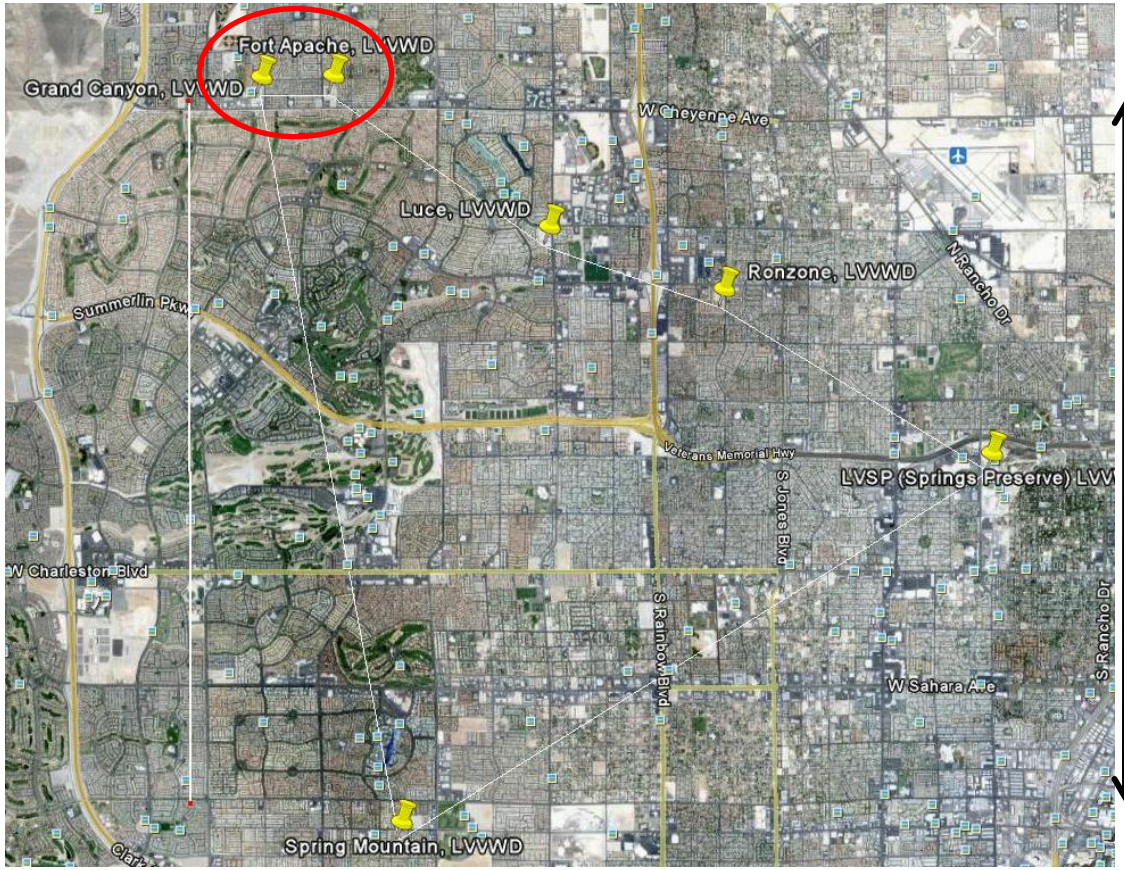
Is the distribution grid ready to accept large-scale photovoltaic deployment? State of the art, progress, and future prospects

Martin Braun[1,2*], Thomas Stetz[2], Roland Bründlinger[3], Christoph Mayr[3], Kazuhiko Ogimoto[4], Hiroyuki Hatta[5], Hiromu Kobayashi[5], Ben Kroposki[6], Barry Mather[6], Michael Coddington[6], Kevin Lynn[7], Giorgio Graditi[8], Achim Woyte[9] and Iain MacGill[10]

What About Over Short Distances?

Case Study: Los Vegas Valley Water District

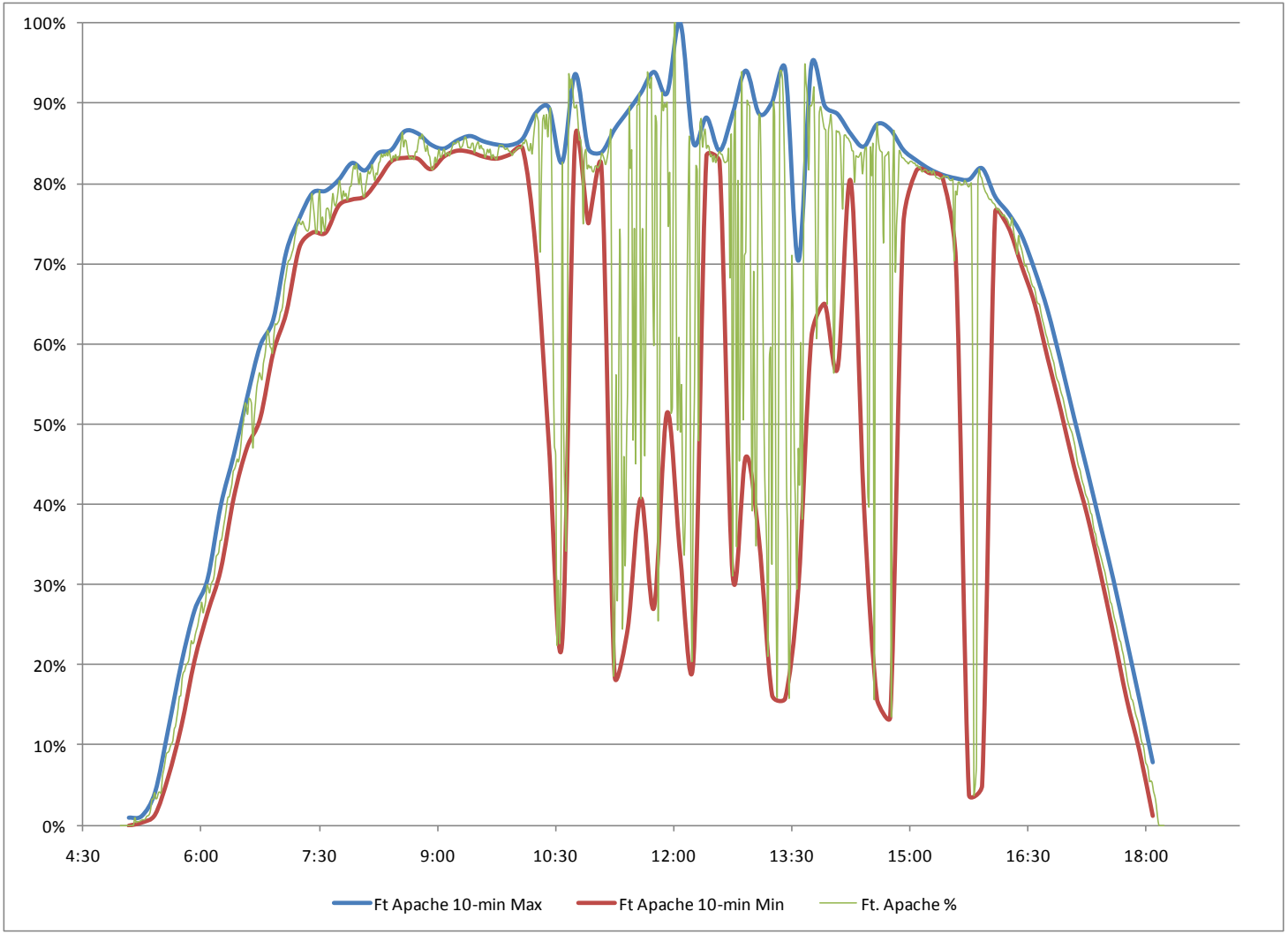
Six Distributed Sites. Minimum Distance: Grand Canyon – Ft. Apache = 1 km



10 km

Top – Grand Canyon
Bottom - Ronzone

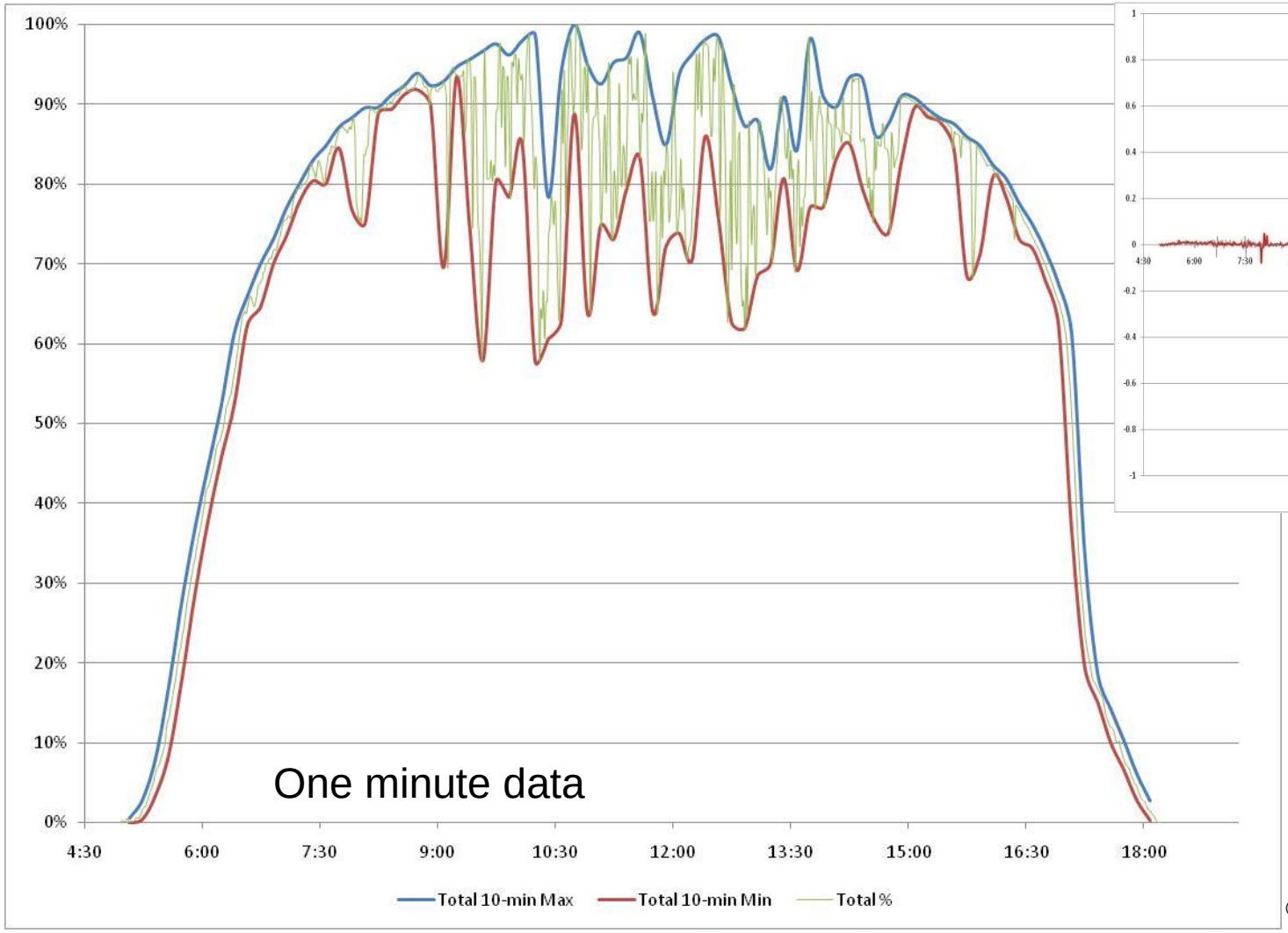
Single Site – Highly Variable Day

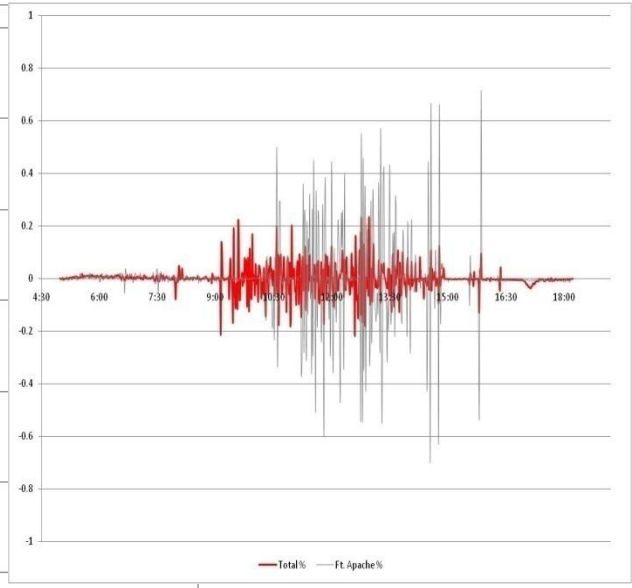


One minute data (Ft. Apache)

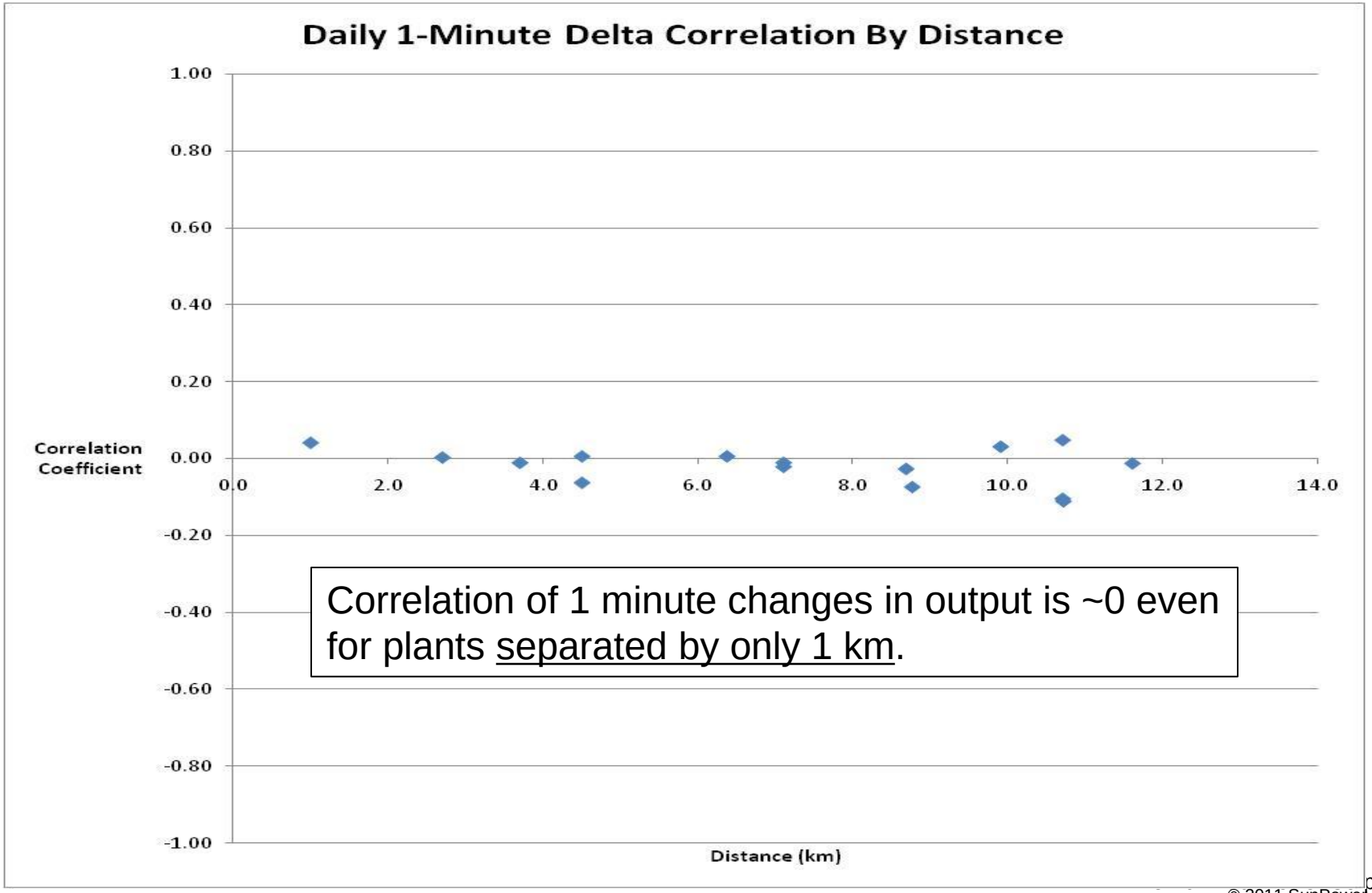
Partly cloudy day, highly variable conditions.

6 Sites, 1-10 km apart (same day)



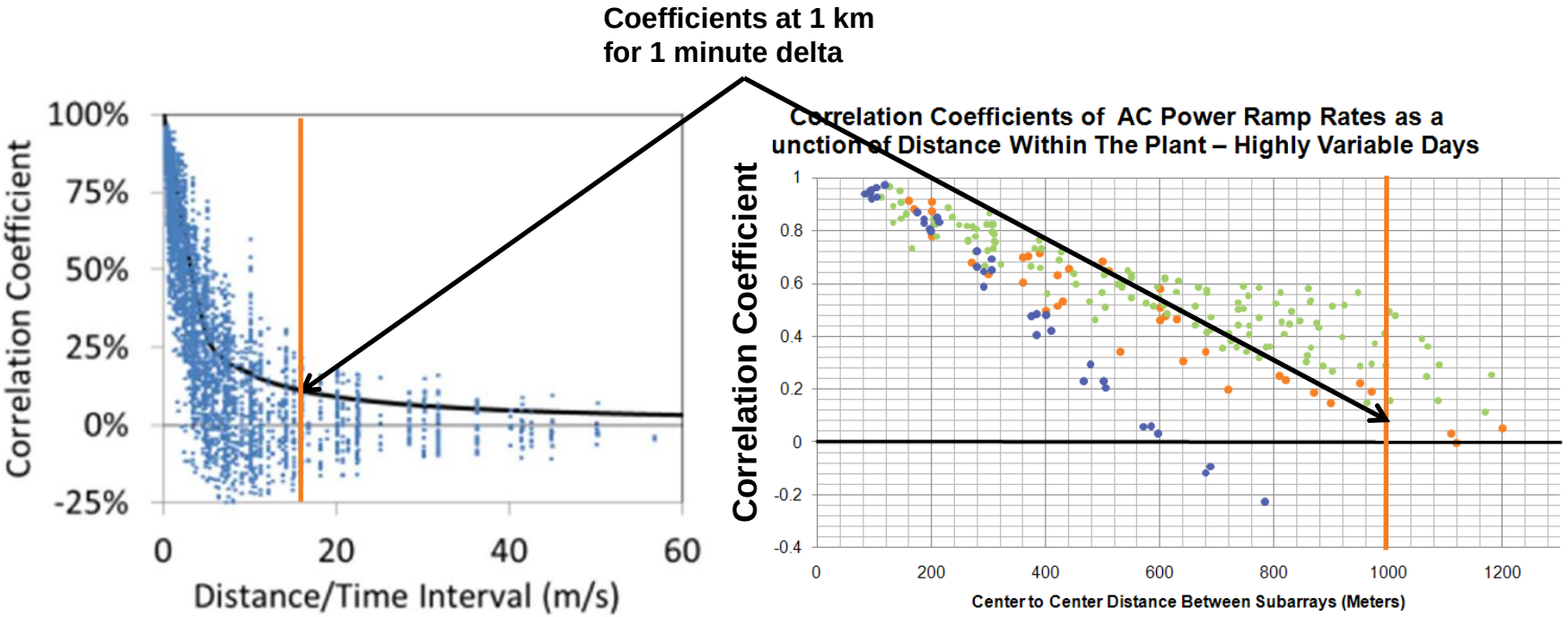


Why? 1-Minute Changes Are Uncorrelated



Correlation of 1 minute changes in output is ~0 even for plants separated by only 1 km.

More Examples of Diversity Over Short Distances



Analysis by Clean Power Research based on 25 node irradiance sensor network on 4 km^2 footprint (Napa CA), high variability day

Analysis of 1-minute deltas on high variability days from 3 operating mid-size plants (10 MW – 25 MW) in desert, tropical, and midwestern climates

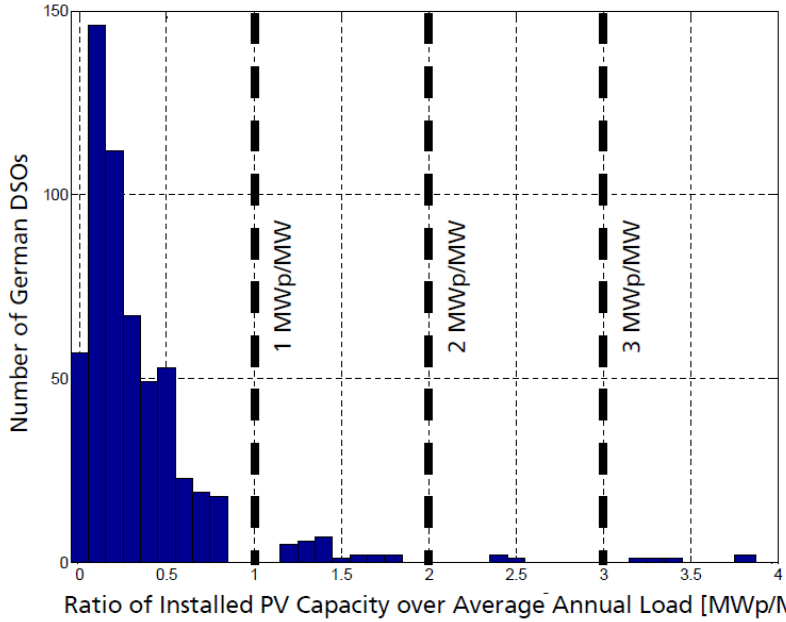
- Consistently, **correlations of 1-minute deltas approach zero at ~1 km (+/- 500 m?).**
- **Zero-correlation distance for 1-second deltas could be as small as 20 meters.**
- **Geographical diversity likely mitigates voltage impacts on distribution systems.**

High Penetration In Germany – 28,000 MW DG

Germany Today:

- *Distributed:* 1.1 million systems, 85% rooftop
- *Concentrated:* ~70% in S. Germany
- Penetration exceeding 100% of feeder minimum load is fairly common

Ratio of Installed PV Capacity over Average Annual Load [MWp/MW]

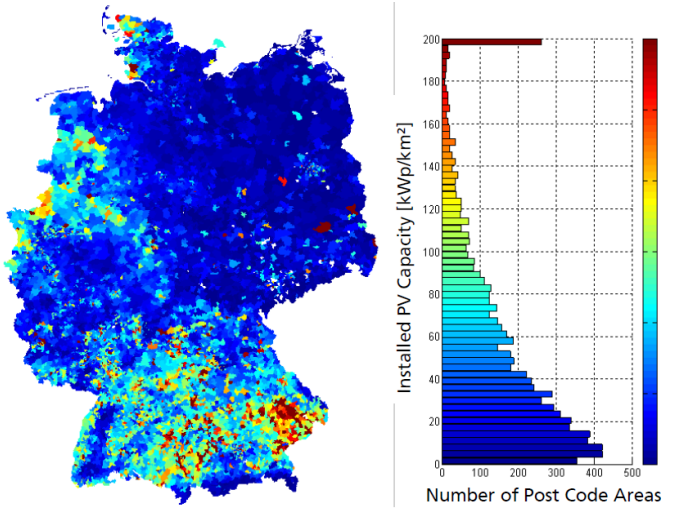


Average Ratio:
0,34 MWp/MW

~10% of the DSOs:
Ratio > 1 MWp/MW

8 DSOs:
Ratio 2-3 MWp/MW

7 DSOs:
Ratio 3-4 MWp/MW



Source: Y.-M. Saint-Drenan 2010 (IWES)

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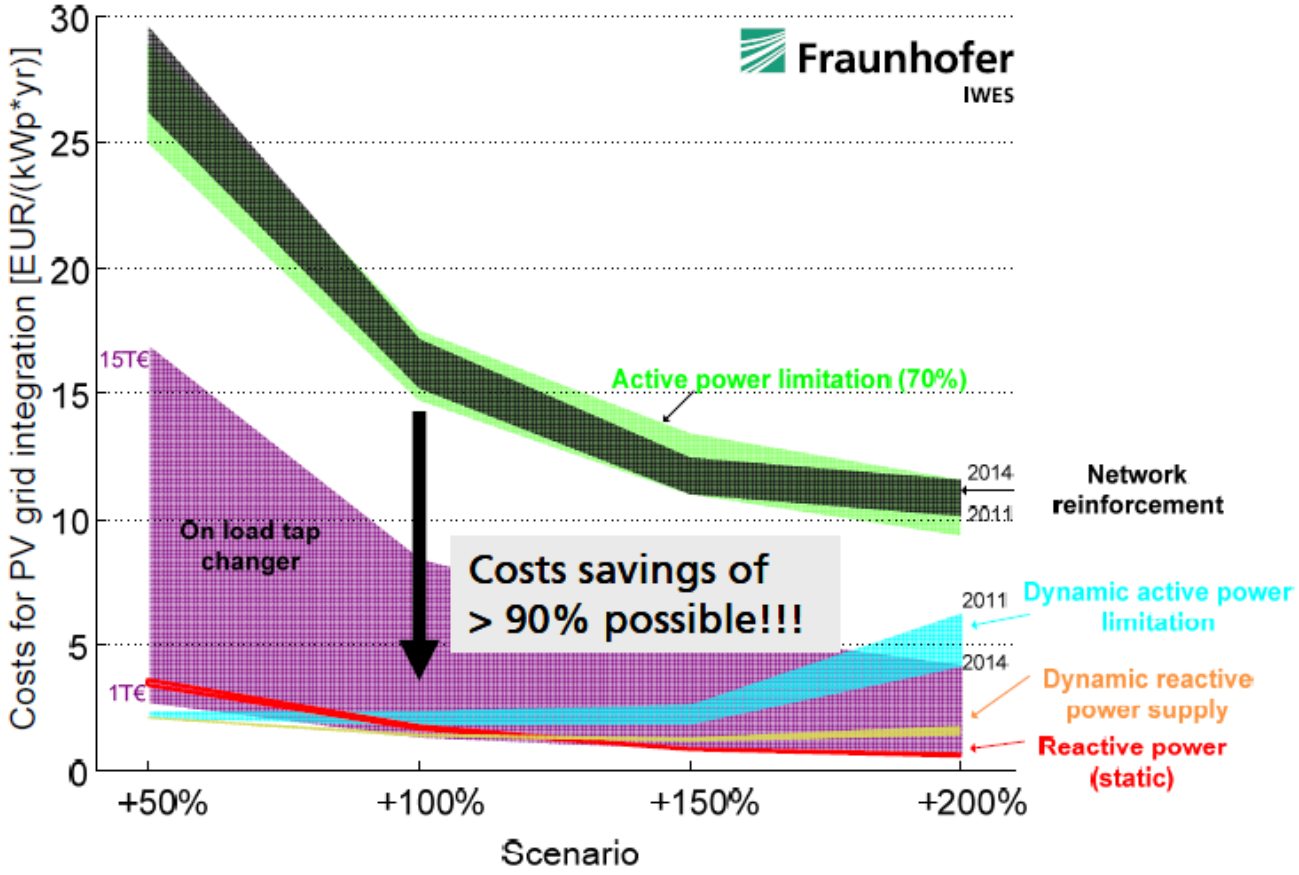
Sources: Braun 2010, IEA PVPS Task 14 Workshop, 2012 SEPA Germany Fact Finding Report

Reactive Power Support Key?

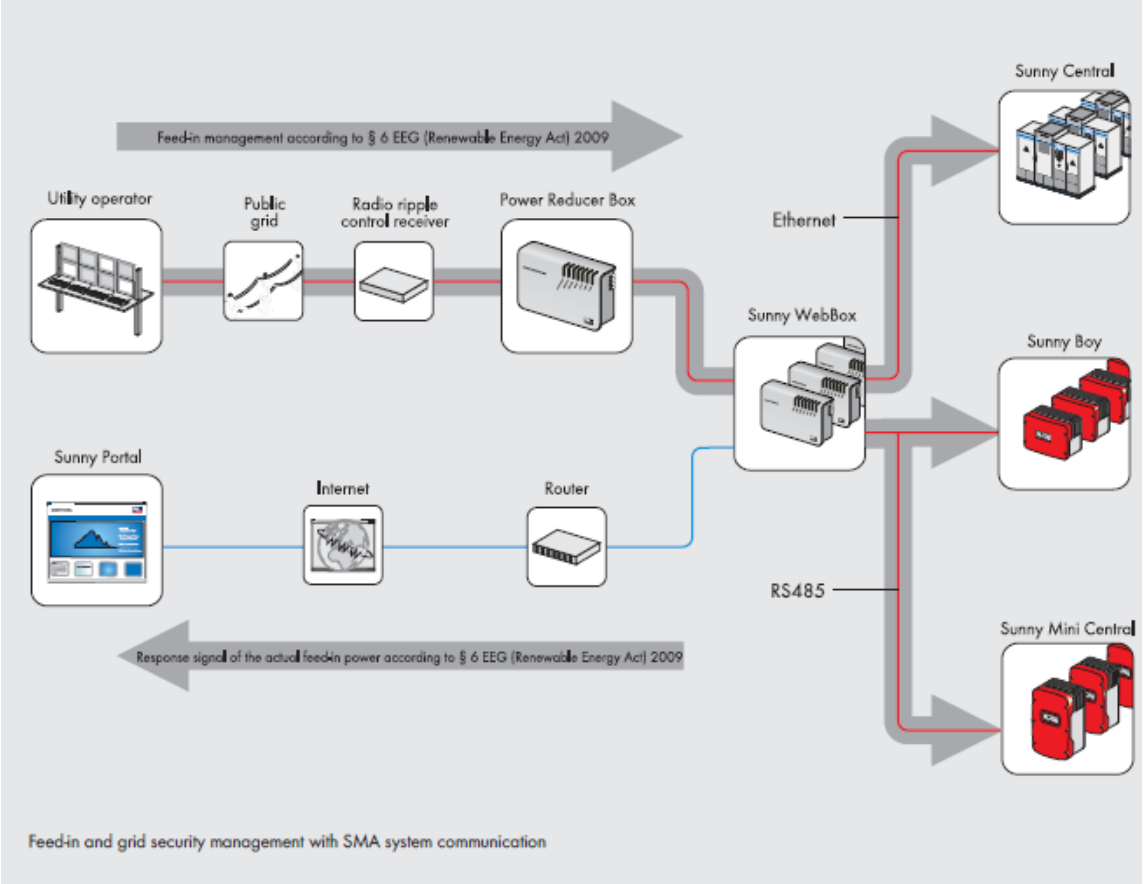
Significant Costs Reduction Potential for PV deployment (exemplary German low voltage grid)



Source: T. Stetz, M. Braun (IWES) 2011

Germany – Communications & Monitoring

Example: Operation of SMA "Power Reducer Box" For 100+ kW Systems



Courtesy of SMA

- Communication from utility to PV system is unidirectional via ripple control.
- Enables real and reactive power control in conjunction with local autonomous droop functions.
- Monitoring is typically provided, but to PV system owner / operator, not directly to utility; monitoring is via public broadband.
- Transmission system operators contract for PV output estimates and forecasts provided by 3rd parties. Forecasts are based on modeling aggregate regional PV output. Achieving 4-5% RMSE in practice.
- Demonstrates that deterministic, 2-way communication to endpoints (i.e. "smart grid") is not the only, or necessarily the best option to manage DG.

SunPower Grid Integration

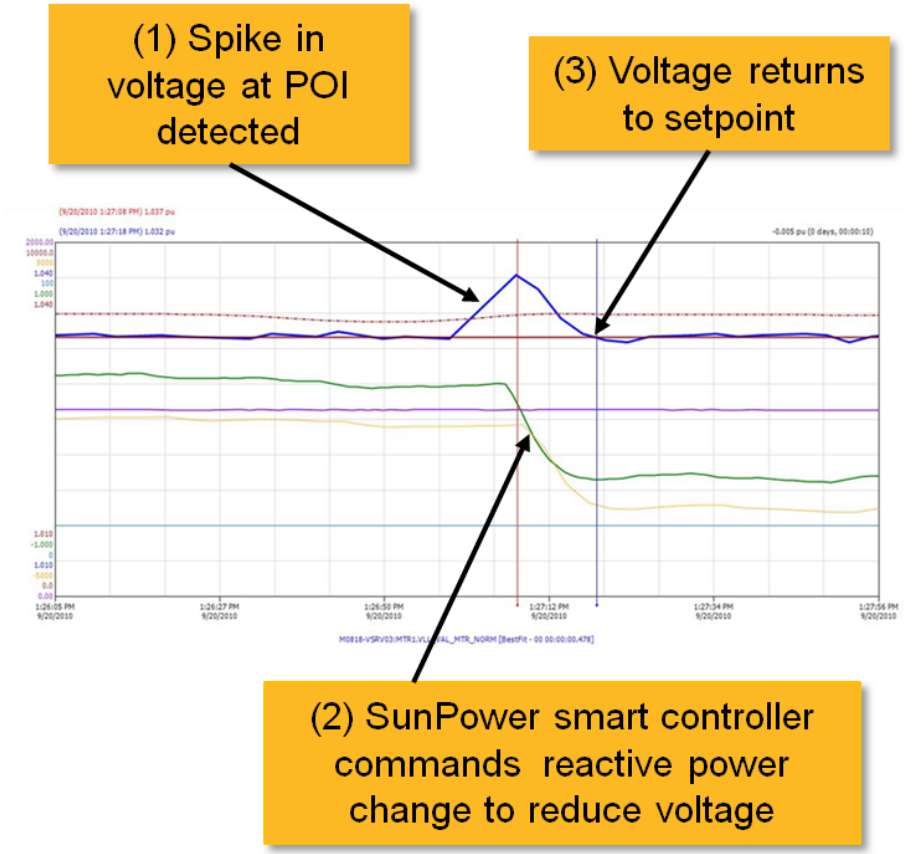
SunPower offers sophisticated PV control options:

- Automatic Voltage Regulation
- Power Factor Control
- Active Curtailment
- Droop Response
- Dynamic Voltage Control (AVR)

Primarily apply to utility-scale and wholesale DG

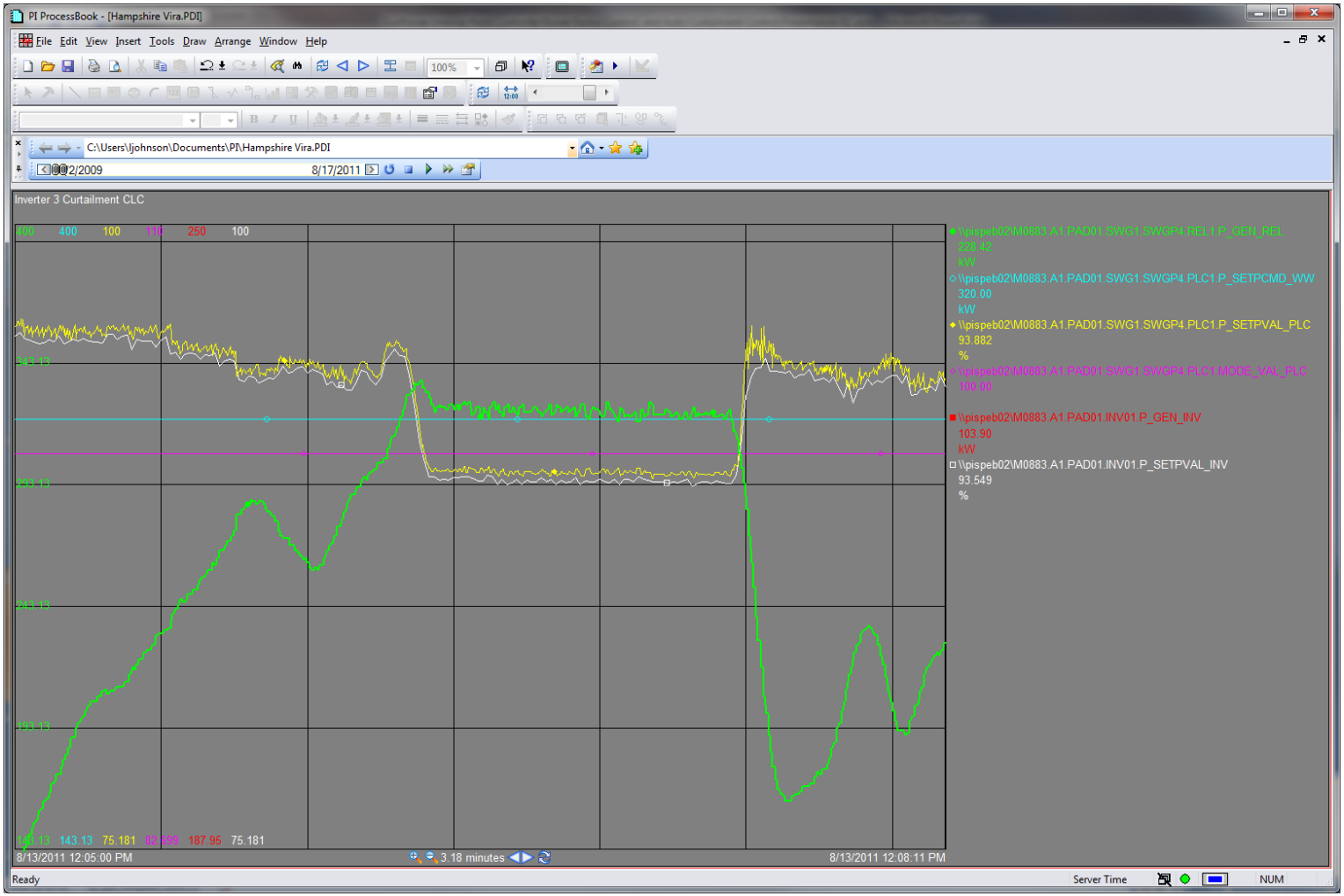
Some features can be implemented “behind the meter”

Reactive Power Control / Voltage Regulation



SunPower has pioneered the implementation of AVR in large-scale PV plants.

Active Power Management Capability



Green = Net Power Flow, Cyan = Backfeed limit setpoint, Yellow = Inverter curtailment %.

Summary

- Geographical diversity needs to be accounted for when assessing distribution system impacts, especially over small timescales (e.g. <10 minutes)

- Advanced inverters & plant controls provide control options

- Communications, control strategies must be considered carefully; need not be directly linked

- Thorny issues tend to be cost related – tempting to over specify functionality

- Rule 21 / SGIP reform an important first step, if only to create a more transparent interconnection process